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(54) **High voltage switch.**

(57) A spark gap switch includes a housing forming a cavity (104), a first electrode (106), and a second electrode (114). The first electrode has a hollow tubular portion with an inner surface having a generally circular cross-section perpendicular to an axis (112) and extends along the cavity from one end of the cavity. The second electrode (114) has a generally circular cross-section perpendicular to the axis and extends along the cavity from the other end of the cavity. The second electrode extends at least partially into the hollow tubular portion formed by the first electrode.

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This invention relates generally to high voltage switches and more particularly to a spark gap switch triggered by a change in pressure.

Spark gap switches have many uses in high power applications with short switching time intervals or short pulse durations. The basic spark gap switch includes a housing and a pair of electrodes. When a high voltage is applied to the electrodes, an arc is created between the electrodes and current is allowed to pass through the switch.

Typically, the main electrodes of a spark gap switch are basically pins or rods with the ends pointing at each other. Therefore, when an arc forms between the electrodes all the current passes in the area between the ends of the electrodes. This creates a high current density and furthermore a high inductance switch.

However, some applications require faster switches with shorter on/off time intervals and have higher power requirements than is typical of conventional switches. Furthermore, reliability and a longer useful life are desirable. Safety, that is, the prevention of random firings of the switch, is another key issue.

The key factors in achieving these requirements are lowering the inductance of the switch and decreasing the electrical losses. The cleanliness of the switch's inner surfaces also influences safety, reliability and the useful life of the switch.

According to the present invention a switch comprises a housing forming a cavity; a first electrode extending along the cavity having a hollow tubular portion with an inner surface which has a generally circular cross-section perpendicular to the axis of the tubular portion; and a second electrode having first and second ends of which the first end is connected to the housing, and the second end has a generally circular cross-section substantially perpendicular to the axis and extends in the cavity along the axis at least partially into the hollow tubular portion of the first electrode.

In the accompanying drawings:

Fig. 1 is a stylized representation of a spark gap switch having first, second, and third electrodes, according to an embodiment of the present invention;

Fig. 1A is a stylized representation of a spark gap switch having first and second electrodes, according to a second embodiment of the present invention;

Fig. 1B is a stylized representation of the second electrode of Figs. 1 and 2 and a trigger electrode, according to an embodiment of the present invention;

Fig. 2 is a stylized representation of an alternate embodiment of the second electrode of Figs. 1 and 2; and,

Fig. 3 is a block diagram illustrating the operation of the spark gap switch of Fig. 1.

With reference to Fig. 1, a switch 100 having a housing 102 is provided. In the preferred embodiment the housing 102 includes a body 120 and first and second end portions or endcaps 106, 110. The housing 102 has a generally circular cross-section centred about an axis 112. The body 120 and first and second endcaps 106, 110 form a pressurised cavity 104. The first and second endcaps 106, 110 are composed of an electrically conducting material, preferably copper or a copper alloy.

The body 120 is composed of an insulating material. In the preferred embodiment, the body 120 is composed of polycarbonate. The body 120 has an exterior surface or wall 122 which is, preferably, grooved. The body 120 has an interior surface or wall 124 which is also, preferably, grooved.

In the preferred embodiment, the first endcap 106 forms a first electrode. However, the first endcap and the first electrode may be separate.

The first electrode 106 has an inner surface 108. The inner surface 108 has a generally circular cross-section perpendicular to the axis 112. The inner surface 108 extends along the cavity 104 in a first direction along the axis 112, forming a hollow tube.

A second electrode 114 has first and second ends 116, 118 and in the preferred embodiment is connected to the second endcap 110 at the first end 116. The second end 118 of the second electrode 114 has a generally circular cross-section perpendicular to the axis 112. The second end 118 of the second electrode 114 extends into the cavity 104 in a second direction along the axis 112. Preferably, the first and second directions are opposite. In the preferred embodiment, the second end 118 of the second electrode 114 extends at least partially into the hollow tube formed by the first electrode 102.

In one embodiment, the first and second electrodes are composed of a copper alloy. In another embodiment, the second electrode 114 includes a replaceable tip portion. The tip portion is composed of tungsten or a tungsten alloy. A suitable alloy is Elkonite, which consists of tungsten and copper.

In the preferred embodiment, the second electrode 114 is tapered. That is, the thickness of the second end portion 118 of the second electrode 114 decreases towards the end, thereby increasing the distance between the first and second electrodes 106, 114. The tapering of the second electrode 114 minimizes the firing or arcing of the switch 100 toward the end of the second electrode 114 and reduces wear.

The operating characteristics of the switch 100 may be modified by varying the distance between the first and second electrodes 106, 114. In the preferred embodiment, this is accomplished by changing the outside diameter of the second electrode 114. With reference to Fig. 2, an alternate second electrode 202 for the switch 100 of Fig. 1 is shown. As illustrated, for

a small diameter electrode, the first end portion is flanged to add mechanical stability.

In the preferred embodiment, the switch 100, includes a third electrode 130. The third electrode 130 is electrically connected to the first electrode 106. The third electrode 130 has a generally circular cross-section perpendicular to the axis 112 and extends along the axis 112 towards the second electrode 114.

In the preferred embodiment, the second electrode 114 forms a second hollow tube. The third electrode 130 extends into the second hollow tube. The distance between the second and third electrodes 114, 130 (D1) is preferably less than the distance between the first and second electrodes 106, 114 (D2).

The switch 100 may include an insulating tubular insert 132 situated in the hollow tube formed by the second electrode 114. The insulating tube 132 reduces the weight, adds mechanical stability, and reduces the gas volume for faster on/off cycling response. Preferably, the insulating tube 132 is also composed of a polycarbonate and forms part of a gas outlet port 126.

A quartz window 136 permits introduction of a brief pulse of ultraviolet radiation to trigger the switch 100. The use of the quartz window 136 to trigger the switch 132 is used as an alternative triggering method or to assist at higher repetition rates to fire the switch with appropriate synchronization.

A fibre optic probe 134 senses the optical spectra emitted when the switch is firing. As shown, the probe 134, penetrates approximately halfway into the body 120 because polycarbonates allow visible light to pass.

The housing 102 is held together by a plurality of screws. In the preferred embodiment, the screws are composed of nylon. Sealing gaskets or O-rings seal the juncture between the endcaps 106, 110 and the body 120.

With reference to Fig. 1A, in an alternative embodiment, the switch 100 includes at least one gas inlet port 128', 128", in the body 120 of the housing 102 (two are shown).

The switch 100 can be triggered by three methods, individually or in combination: ultraviolet radiation (described above), pressure (described below), and by a trigger electrode 138, as shown in Fig. 1B. In the preferred embodiment, the trigger electrode 138 includes a copper tube 140 and a brass ball 142. The copper tube 140 passes through the centre of the insulator 132 and the second electrode 114. In the preferred embodiment, the trigger electrode 138 is fed a trigger pulse signal through a screw 146 and washer 144 arrangement, as shown. The trigger pulse signal creates an arc between the trigger electrode 138 and the second electrode 114 by locally exerting the electric field. The arc ionizes the gas in the cavity 104, triggering an arc between the first and second electrodes 106, 114. An insulator 148 isolates the screw 146 from the second electrode 114.

With reference to Fig. 3, a means 300 forms a short circuit between the first and second electrodes 106, 114. The means 300 controllably increases and decreases the pressure of the gas within the cavity 104 between an open value and a closed value. The gas acts as an insulator between the first and second electrodes 106, 114 under the open value and as a short circuit between the first and second electrodes 106, 114 under said closed value.

The switch 100 is opened and closed to supply electrical power to a load 302. In the preferred embodiment, the load 302 is connected to the first electrode 106. The second electrode 114 is electrically connected to a high voltage power supply 308.

A high pressure gas supply 304 is provided for pressurizing the cavity 104. In the preferred embodiment the cavity 104 is pressurised with sulphur hexafluoride gas, SF<sub>6</sub>.

A pressure release valve 306 releases the pressure from the cavity 104.

In the preferred embodiment, the cavity 104 is pressurised and unpressurised by actuation of the high pressure gas supply and pressure release valve 304, 306 through the gas inlet port 128 and the gas outlet port 126, respectively, by a controlling means 310.

#### Industrial Applicability

In operation, the switch is highly reliable, durable, compact, low cost, and easily serviced.

As described, the switch 100 is generally operated by controllably increasing and decreasing the pressure within the switch 100. This has two advantages. First, it automatically cycles the gas within the cavity 104, thereby lowering the temperature. This aids in keeping the electrodes cool. Second, by changing the gas within the switch 100 between firings, contaminants are removed from the cavity 104. Furthermore, when the gas is released, the pressure gradient created between the first and second electrodes 106, 114 favours the formation of an arc discharge away from the end of the second electrode 114. This produces a lower and more uniform current density.

The controlling means 310 closes the switch 100 by opening the pressure relief valve 306 and releasing the SF<sub>6</sub> gas. Typically, the switch 100 is pressurised to approximately 6 atmospheres. However, pressures up to 12 atmospheres may be used.

When the pressure reaches a certain value (depending upon the switch characteristics) the switch 100 will fire. When the switch 100 fires, an arc is formed between the first and second electrodes 106, 114. The electrodes 106, 114 are designed to provide greater surface area for current to flow between the first and second electrodes. This effectively decreases the current density, the ohmic resistance, and the inductance of the switch 100.

The third electrode 130 further reduces the resistance and inductance of the switch 100. In operation, within nanoseconds of firing of the switch an arc will form between the second and third electrodes 114, 130. This second arc occurs after the first arc because the gap between the second and third electrodes, 114, 130 (D1), is slightly larger than the gap between the first and second electrodes 106, 114 (D2). Furthermore, the first arc produces ionizing ultraviolet radiation which expedites the triggering of the second arc.

The grooves in the inner and outer surfaces 122, 124 of the body 120 aid in increasing the voltage insulation between the endcaps and electrodes 106, 110, 114, 130. The tapering at the end of the second electrode 114 helps reduce the wear at the tip, switching on speed, further reduces the inductance, and increases the lifespan of the electrode 114.

Furthermore, the rugged design and ease of dismantling and assembly make the switch very serviceable in the field.

The switch has been tested between 15-300 kV (in an external air environment). However, by scaling the design up, the switch should be able to handle voltages up into the megavolt range. The operating characteristic of the switch 100 can be modified by changing the diameters of the first and/or second electrode 106, 114 or by scaling the dimensions of the entire switch 100.

#### Claims

1. A switch comprising a housing (102) forming a cavity (104); a first electrode (106) extending along the cavity having a hollow tubular portion with an inner surface (108) which has a generally circular cross-section perpendicular to the axis (112) of the tubular portion; and a second electrode (114) having first and second ends (116, 118) of which the first end is connected to the housing, and the second end has a generally circular cross-section substantially perpendicular to the axis (112) and extends in the cavity along the axis at least partially into the hollow tubular portion of the first electrode.
2. A switch according to claim 1, wherein the tubular portion of the first electrode (106) defines one end part of the cavity (104).
3. A switch according to claim 1 or claim 2, the first electrode (106) is provided nearer one end of the cavity and the second electrode (114) extends along the axis (112) into the hollow tubular portion of the first electrode in a direction away from the other end of the cavity.

4. A switch according to any one of the preceding claims, wherein the housing includes a body (120) composed of an insulating material.
5. A switch according to claim 4, wherein the insulating material comprises a polycarbonate.
6. A switch according to claim 4 or claim 5, wherein the body (120) has a generally circular cross-section perpendicular to and centred about the axis (112).
7. A switch according to any one of claims 4 to 6, wherein the body (120) has an exterior wall surface (122) which is grooved.
8. A switch according to any one of claims 4 to 7, wherein the body (120) has an interior wall surface (124) which is grooved.
9. A switch according to any one of the preceding claims, wherein the cavity (104) is arranged to be pressurised.
10. A switch according to claim 9, wherein the cavity (104) is pressurised with sulphur hexafluoride gas.
11. A switch according to any one of the preceding claims, which includes means (300) for forming a short circuit between the first and second electrodes (106, 114).
12. A switch according to claim 11 when dependent on claim 9 or claim 10, wherein the short circuit-forming means (300) includes means for controllably increasing and decreasing the pressure of the gas within the cavity (104) between an open value and a closed value, wherein the gas acts as an insulator between the first and second electrodes (106, 114) under the open value and as a short circuit between the first and second electrodes under the closed value.
13. A switch according to any one of claims 9, 10 or 12, wherein the cavity has a gas inlet port (128) and a gas outlet port (126).
14. A switch according to any one of claims 1 to 8, wherein the cavity has a quartz window (136) and wherein the switch is arranged to be triggered by ultraviolet radiation.
15. A switch according to any one of claims 1 to 8, including a trigger electrode (138), the switch being arranged to be triggered by a trigger pulse signal applied to the trigger electrode.

16. A switch including a third electrode (130).
17. A switch according to claim 16, wherein the third electrode (130) is electrically connected to the first electrode (106). 5
18. A switch according to claim 16 or claim 17, when dependent on claim 2 or claim 3, wherein the third electrode (130) has a generally circular cross-section perpendicular to the axis (112) and extends along the axis (112) in a direction away from the one end of the cavity. 10
19. A switch according to claim 18, wherein the second electrode (114) forms a second hollow tubular portion and the third electrode (130) extends into the second hollow tubular portion. 15
20. A switch according to claim 19, wherein the distance between the second and third electrodes (114,130) is less than the distance between the first and second electrodes (106,114). 20

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FIG. 1A.

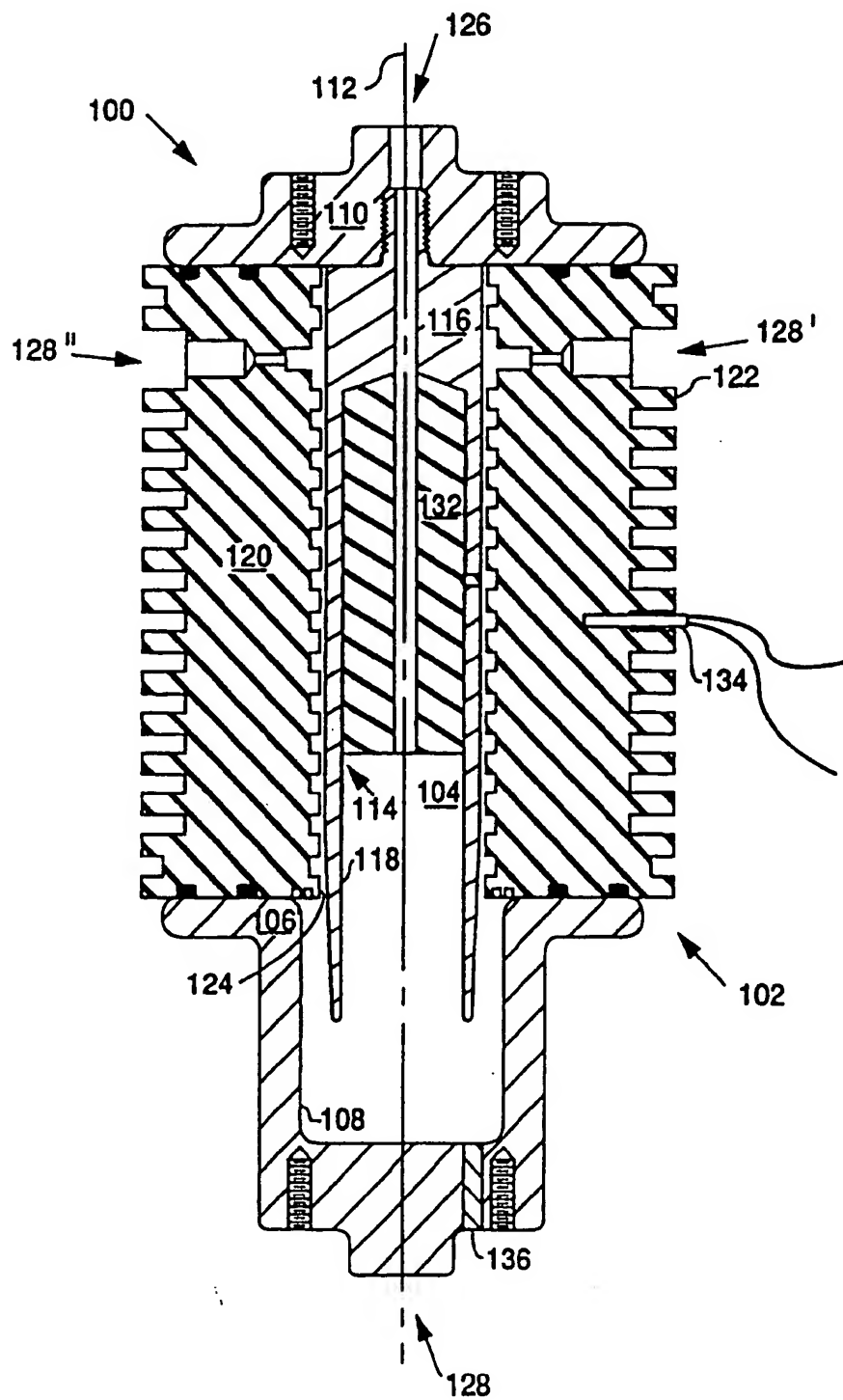


FIG. 1B.

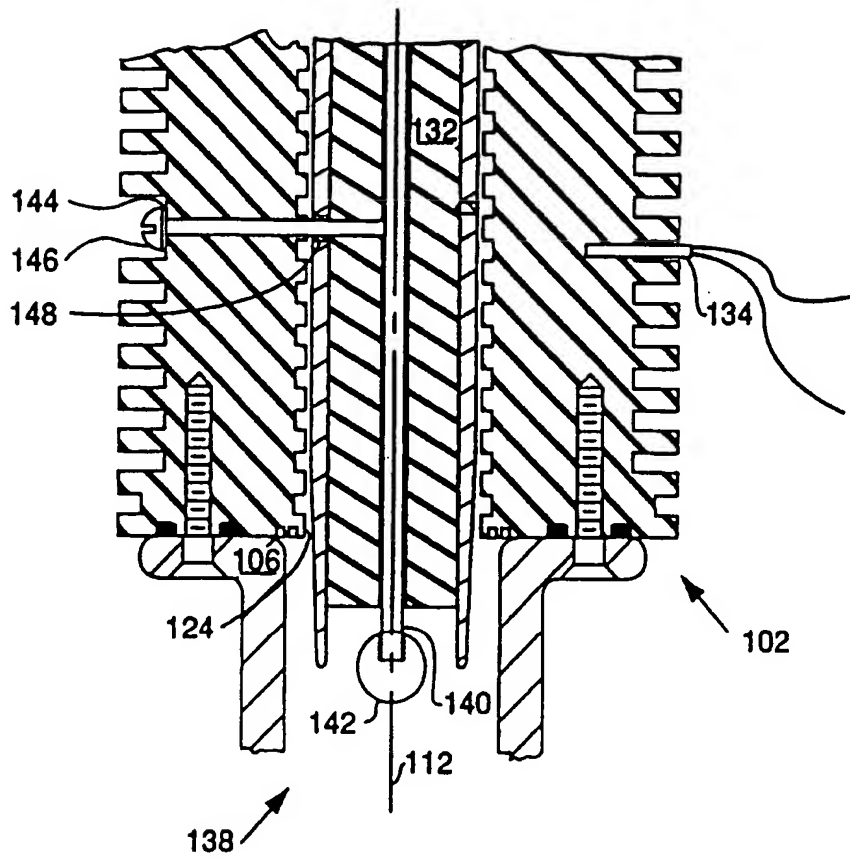




FIG. 2.

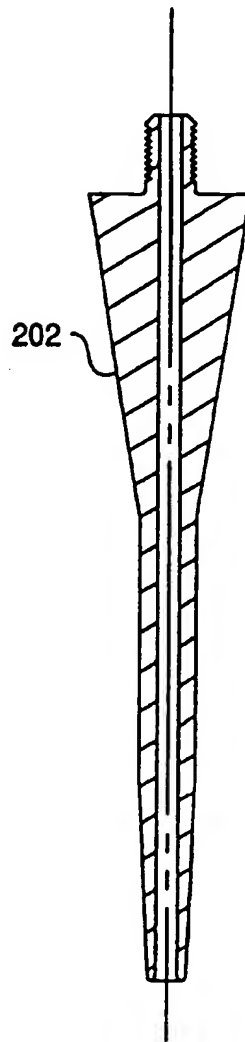
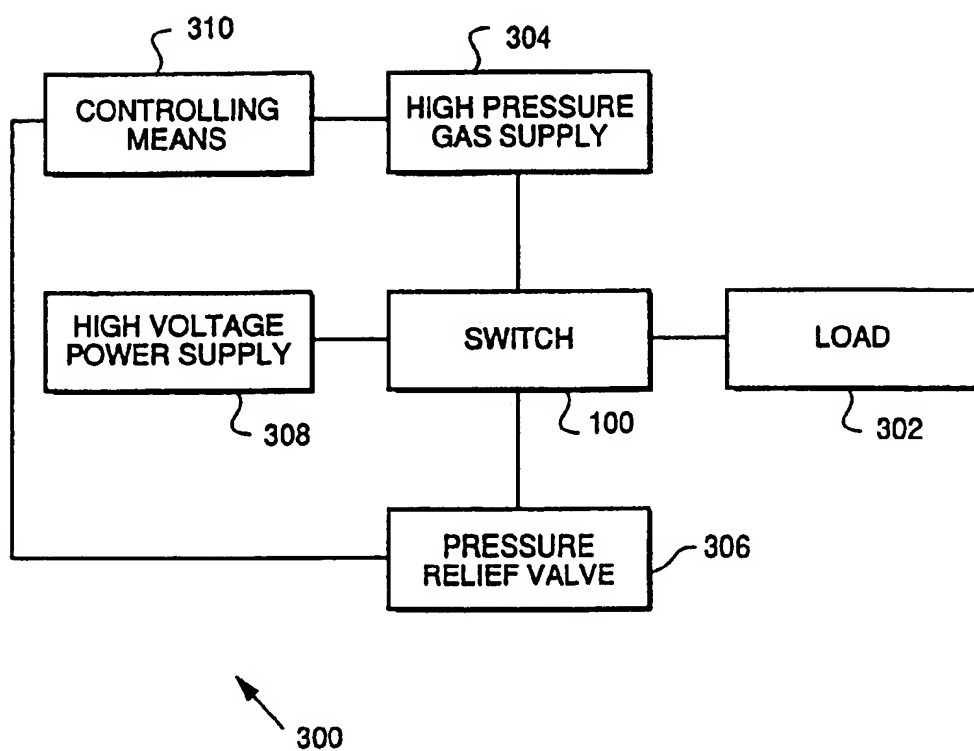


FIG. 3.





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# EUROPEAN SEARCH REPORT

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EP 92 31 0359

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X Y	DE-A-3 523 299 (BERU RUPRECHT)  * column 2, line 43 - column 3, line 4 * * column 3, line 18 - line 50; figures 1,5 * ---	1-4,6 9,11,14	H01T2/02 H01T1/22
X A	EP-A-0 229 303 (CERBERUS) * claims 1,12-14; figures 1,2 * ---	1-4,6,9 10	
X	MEASUREMENT SCIENCE AND TECHNOLOGY vol. 2, no. 9, September 1991, BRISTOL GB pages 873 - 875 BABY ET AL 'A low-inductance, long-life, triggered spark gap switch for Blumlein-driven lasers'  Y *Introduction; Figure 1* ---	16        10	
X Y A	US-A-4 853 939 (KOKAWA)  * column 1, line 11 - line 14 * * column 1, line 63 - column 3, line 8; figure 1 * ---	16,18-20 9-11 1,13	TECHNICAL FIELDS SEARCHED (Int. Cl.5)  H01T
X	IEE PROCEEDINGS A. PHYSICAL SCIENCE, MEASUREMENT & INSTRUMENTATION, MANAGEMENT & EDUCATION REVIEWS vol. 135, no. 1, January 1988, STEVENAGE GB pages 56 - 58 ALLEN ET AL 'A photon-triggered spark gap' *Introduction; Experiment* ---  -/--	16	
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 15 FEBRUARY 1993	Examiner NIELSEN K.G.
<p><b>CATEGORY OF CITED DOCUMENTS</b></p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons * : member of the same patent family, corresponding document</p>			

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